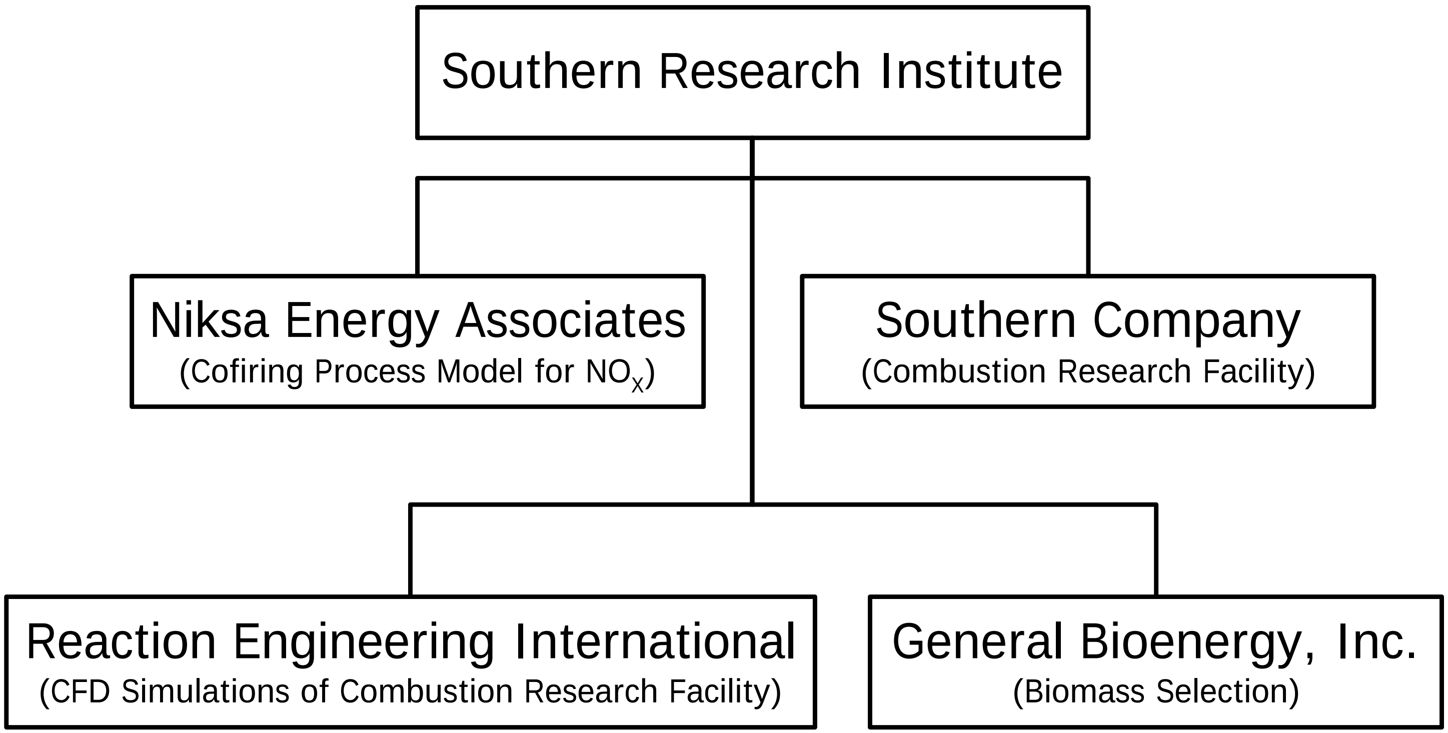
SOUTHERN RESEARCH
INSTITUTE

Cooperative Agreement No. DE-FC26-00NT40895

Development of a Validated Model for Use in Minimizing NO_X Emissions and Maximizing Carbon Utilization When Cofiring Biomass with Coal

Project Team



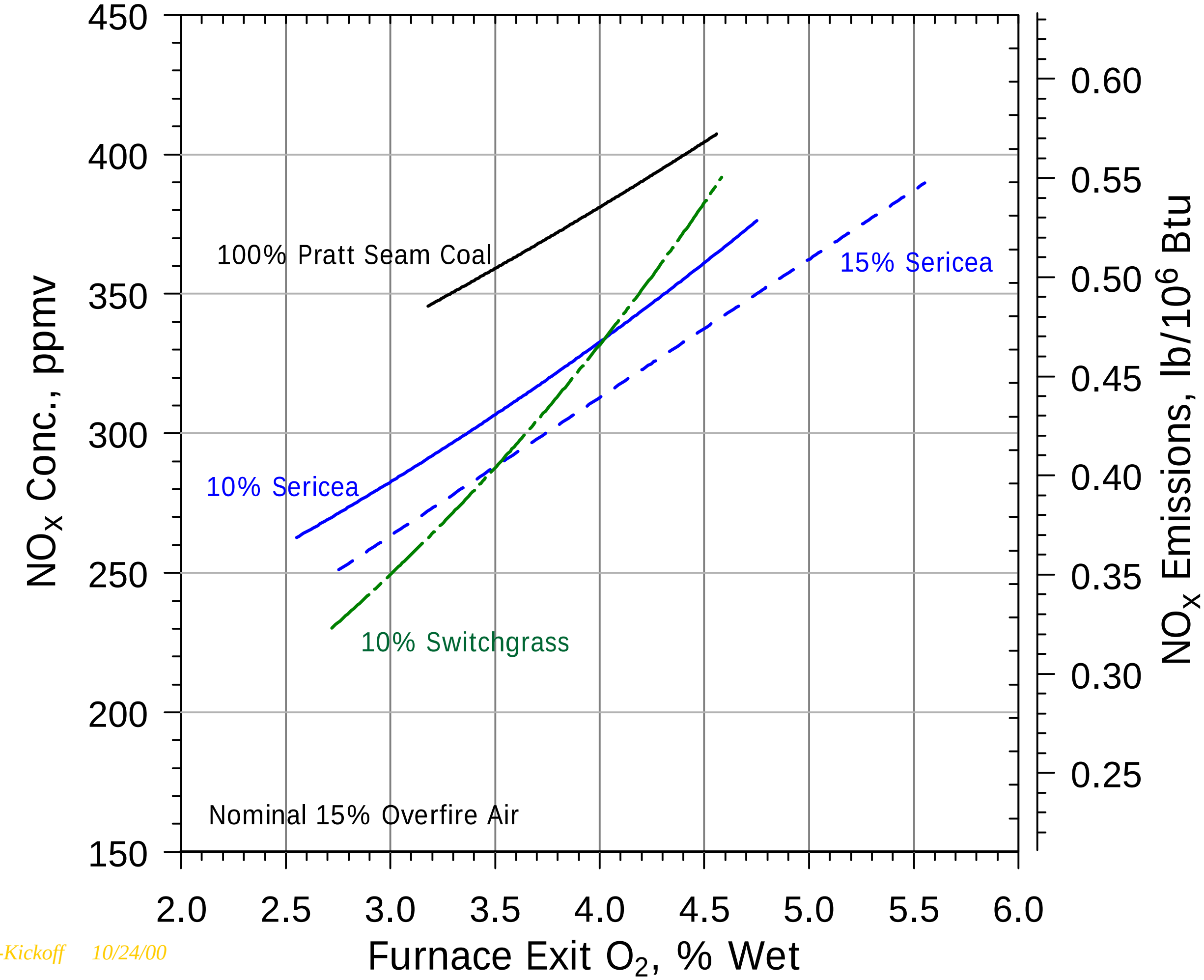
Specific Program Objectives

- Develop a consistent, extensive biomass cofiring database
  - relationships between NOx and biomass cofiring parameters
  - effects on flame stability, carbon burnout, slagging and fouling, and particulate and gaseous emissions
- Develop and validate a biomass cofiring model
  - forecast NOx and LOI for given fuel combination with specified cofiring configuration
  - optimize cofiring configuration to minimize NOx and unburned carbon for specified fuels

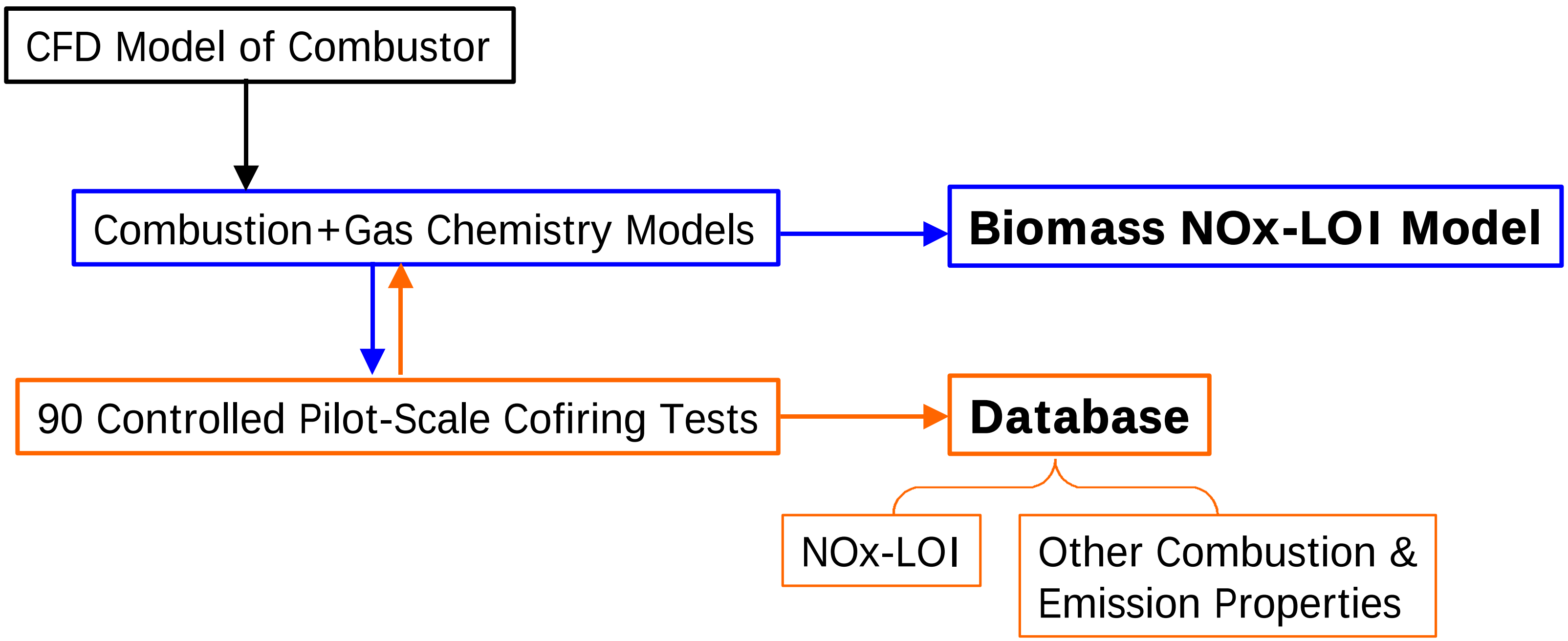
Reported Effects of Biomass Cofiring on NO_X Emissions

Plant	Biomass	%	NO_X Result	Reference
Hammond	Wood	13	No effect	Boylan, et al., 1992
Kraft	Wood	0-30	Reduced > fuel N	Boylan, et al., 1994
Greenidge Station	Dry wood	10	No effect	Prinzing et al, 1996
Greenidge Station	Wet wood	10	Reduced	Prinzing et al, 1996
Madison Gas & Electric	Switchgrass	14	No effect	Ragland et al, 1996
Allen Fossil Plant	Wood	0-20	Reduced > fuel N	Tillman et al, 1996
Sandia Pilot	Wood, switchgrass	0-66	Reduced $\propto$ to fuel N	Baxter and Robinson, 1999
Seward, Allen, Michigan City	Wood	0-20	Reduced < fuel N on average	Tillman, Plasynski, and Hughes, 1999

NO_X in Pilot Combustor Cofiring Tests



Project Flow Chart



Controlled Variables in Cofiring Tests

- biomass types (spanning the range of fuel nitrogen and volatile/fixed carbon ratios that may be encountered),
- biomass particle size,
- coal types (representing the most widely used coals in the utility market),
- fuel mixing conditions,
- burner configurations, and
- time-temperature profile and fuel-air mixing conditions in the combustion region have to match full-scale boilers.

Biomass Selected for Pilot-Scale Tests

Switchgrass: preferred herbaceous crop, 1% fuel N

Dry sawdust: abundant forest products waste, 0.1% fuel N

Wet sawdust: evaluate combustion thermal effects

Coastal Bermuda: grass with relatively high fuel N

Poplar & willow: preferred woody crops, low fuel N

Poultry litter: available farm waste, 5% fuel N

Rice straw: regional agricultural residue

Coal Selected for Pilot-Scale Tests

Analysis	Coal Source: Jacobs Ranch	Lone Mountain	Pratt Seam	Galatia
Proximate (As Received)				
Moisture, %	10.19	1.89	2.25	5.50
Ash, %	6.49	6.50	12.84	6.74
Volatile, %	39.73	34.15	29.02	34.00
Fixed Carbon, %	43.59	57.45	55.89	53.76
Sulfur, %	0.51	0.87	1.49	1.34
Heating Value, %	10356	13958	12919	12876
Ultimate Analysis (Dry)				
Carbon, %	68.97	79.68	74.53	76.60
Hydrogen, %	4.25	4.94	4.33	5.13
Nitrogen, %	0.99	1.55	1.45	1.68
Sulfur,%	0.57	0.89	1.52	1.42
Ash, %	7.23	6.63	13.14	7.13
Oxygen, % (Diff)	17.99	6.31	5.03	8.04
Total, %	100.00	100.00	100.00	100.00
Chlorine, %	0.04	0.03	0.01	0.31

Major Variables within the Test Matrix

Coal

1 Jacobs Ranch - PRB
2 Lone Mountain – Eastern KY
3 Pratt Seam – Alabama, Moderate S
4 Galatia – Illinois Basin

Biomass

1 Switchgrass
2 Poultry Litter
3 Coastal Bermuda Grass
4 Green Hardwood Sawdust (Wet)
5 Green Hardwood Sawdust (Dry)
6 Willow
7 Hybrid Poplar
8 Rice Straw

Burner Configuration

A Tangential Burner
B Generic, Low NO_X Dual Register Burner

Biomass Injection Scheme (Either Burner)

0 Burner alone, no Biomass
1 Co-milled, Injected with Coal
2 Through Center of Burner
3 Off-Axis, Direct Injection into flame
4 Off-Axis, Direct Injection parallel to flame

Biomass Quantity

0% - 100% Coal
10% - 90% Coal
20% - 80% Coal

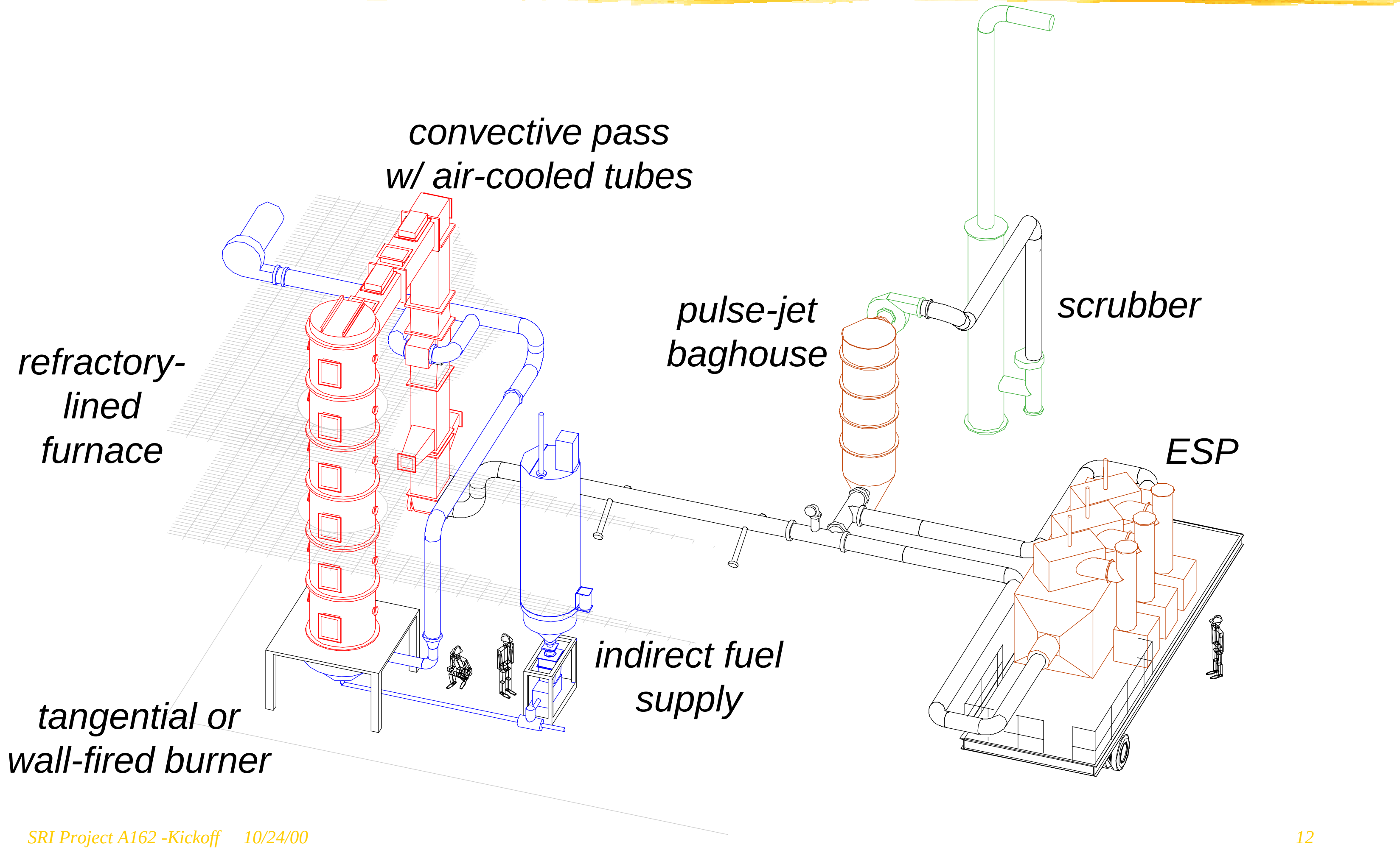
Matrix of Proposed Tests

Test Number	Coal Choice First	Coal Choice Second	Burner-Injection Scheme First	Burner-Injection Scheme Second	Biomass Fuel - % Biomass Day 1	Day 2	Day 3	Day 4	Day 5
1	1		A - 0	A - 2	1 - 0	1 - 10	1 - 20	2 - 10	2 - 20
2	1		A - 2		3 - 10	4 - 10	5 - 10	5 - 20	6 - 10
3	1		A - 2	A - 1	7 - 10	8 - 10	1 - 10	2 - 10	5 - 10
4	1		A - 1		3 - 10	4 - 10	6 - 10	7 - 10	8 - 10
5	1		A - 3		1 - 10	1 - 20	2 - 10	2 - 20	5 - 10
6	1		A - 4		1 - 10	1 - 20	2 - 10	2 - 20	5 - 10
7	2		A - 0	A - 2	1 - 0	1 - 10	1 - 20	2 - 10	2 - 20
8	2		A - 2		3 - 10	4 - 10	5 - 10	5 - 20	6 - 10
9	2		A - 2	A - 1	7 - 10	8 - 10	1 - 10	2 - 10	5 - 10
10	2		A - 1		3 - 10	4 - 10	6 - 10	7 - 10	8 - 10
11	2		A - 3		1 - 10	1 - 20	2 - 10	2 - 20	5 - 10
12	2		A - 4		1 - 10	1 - 20	2 - 10	2 - 20	5 - 10
13	3		B - 0	B - 2	1 - 0	1 - 10	2 - 10	5 - 10	8 - 10
14	4		B - 0	B - 2	1 - 0	1 - 10	2 - 10	5 - 10	8 - 10
15	3	4	B - 1		1 - 10	2 - 10	5 - 10	1 – 10	2 - 10
16	3	4	B - 3		1 - 10	2 - 10	5 - 10	1 – 10	2 - 10
17	3	4	B - 4		1 - 10	2 - 10	5 - 10	1 – 10	2 - 10
18	1	2	B - 2		1 - 10	2 - 10	5 - 10	1 – 10	2 - 10

Grayed areas are used to delineate the second of two conditions within a week of testing.

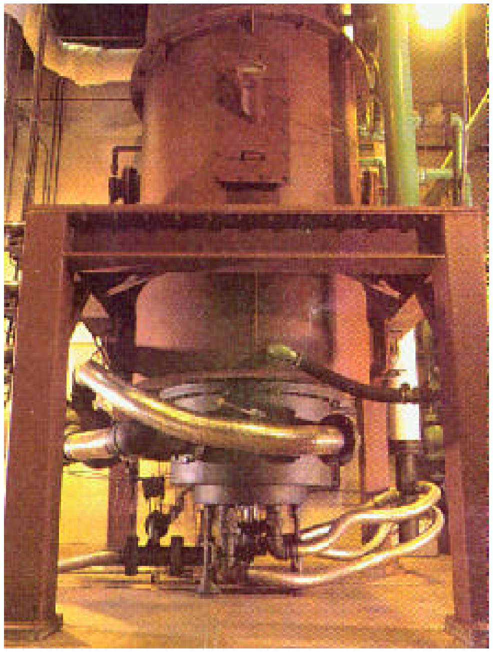
Combustion Research Facility

6 MBtu/hr (1.75 MW_t)

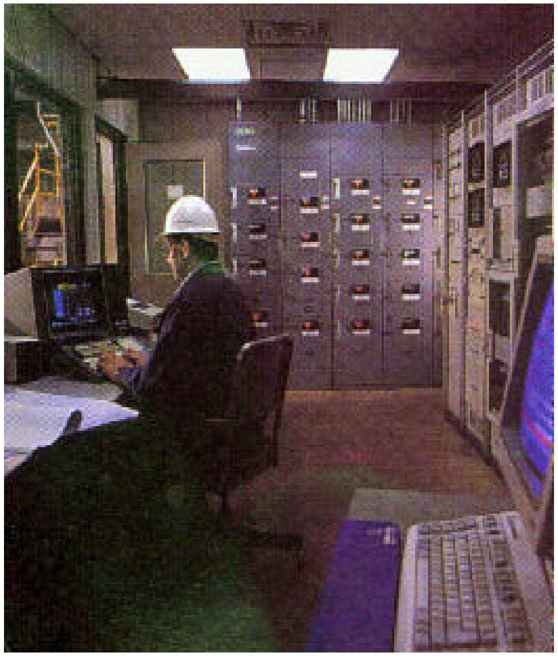


Combustion Research Facility

Furnace & LNB



Control Room



Combustion Research Facility

Raymond Bowl Mill

Furnace Convective Section

Comparison of Pilot-Scale and Full-Scale Results for NO_X and LOI

Date	Coal	Firing Mode	Plant Simulated	NO_X / LOI Pilot Scale	Full Scale Comparison
9/92	N. River	T-fired, conventional	Gaston 5	0.48 lb/MBtu 1.25%	0.60 lb/Mbtu 1.0%
12/92	Shoal Creek	T-fired, Low NOx	Gaston 5	0.47 lb/Mbtu 2.3%	0.5 lb/Mbtu NA
6/94	Gusare (Venezuelan)	Wall-fired Low-NOx	Crist 7	0.46 lb/Mbtu 14.4%	0.59 lb/Mbtu 22 to 41%
11/94	Belle Ayr (PRB)	Wall-fired Low-NOx	Miller 3	0.34 lb/Mbtu <0.1%	0.33 lb/Mbtu NA

Process Modeling

Process Modeling Expands the Value of the Test Data by Interpreting the NO_X and LOI Emissions for Various Fuels and Firing Configurations

Detailed Chemical Mechanisms:

Stephen Niksa, Niksa Energy Associates

Computational Fluid Dynamics:

L. Stan Harding, Reaction Engineering Int.

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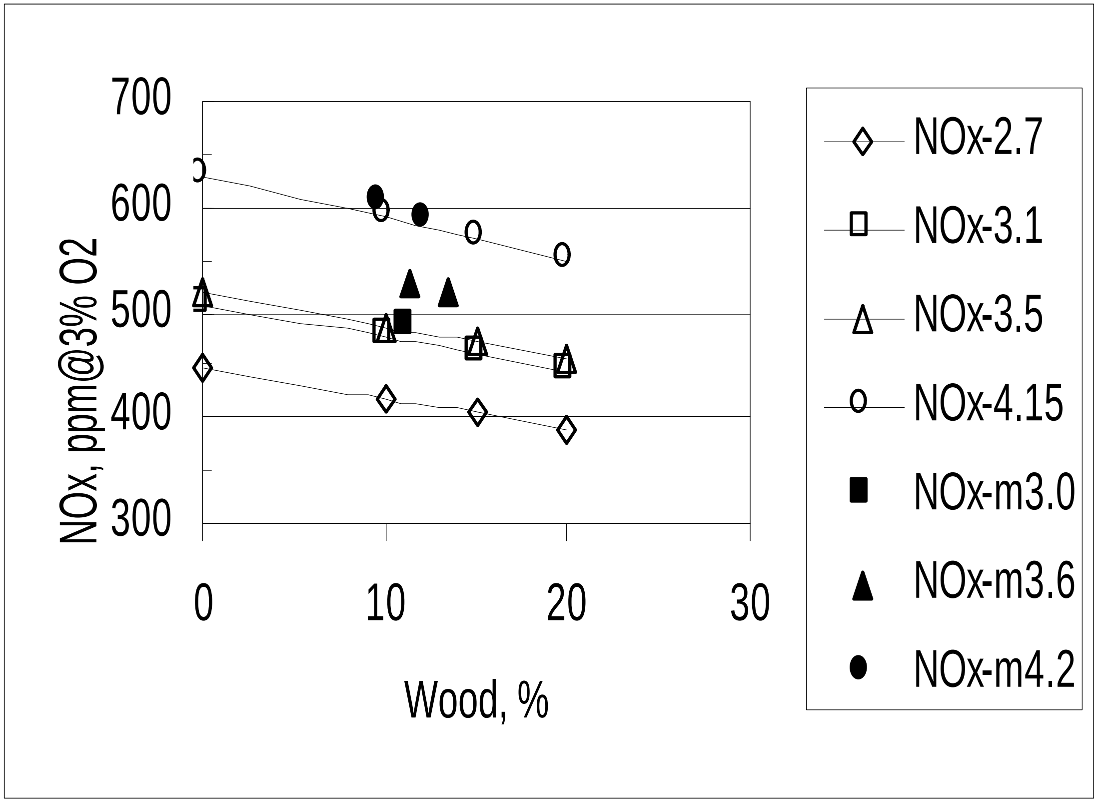
Modeling Background

- EPRI's NO_XLOI Predictor already predicts how NO_X and LOI change when biomass is substituted for part of the coal feed in an existing full-scale utility boiler.
- Distributed to approx. 70 companies.
- Calculation sequence designed for fuel-switching.
- Does not cover biomass cofiring configuration effects.

Predicted NO_X Emissions for Wood Co-Firing Based on bio-FC Are Accurate



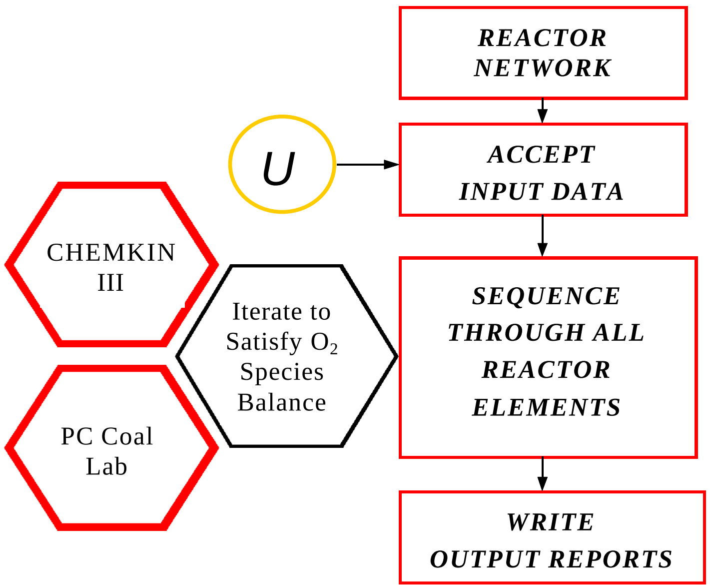
The predictions show the correct trend for different levels of wood co-firing, and are quantitatively accurate for excess O_2 levels from 3 to 4.2 %.

Detailed Chemical Mechanisms and Turbulent Mixing Submodels are Needed for This Application

- Use CFD simulations to characterize the temperature fields and mixing intensities in the SRI test facility.
- Develop an equivalent network of idealized reactor elements for each cofiring configuration.
- Apply detailed chemical submodels to describe fuel-N conversion and burnout throughout the reactor network.

Commercial Software for the Chemical Mechanisms is Easily Incorporated

NEA's Latest NO_X Predictor Combines PC Coal Lab® with Detailed Chemistry via CHEMKIN III



Combine Advanced Coal Decomposition Models With Elementary Reaction Mechanisms for Gas Phase Chemistry.

There Are Three Independent Modeling Aspects

1. An equivalent network of CSTRs and PFRs from the CFD simulations.
2. Fuel Decomposition submodels, including NEA's bio-FLASHCHAIN® for biomass & coal devolatilization and Prof. R. H. Hurt's CBK model for char burnout.
3. Combustion and Fuel-N Conversion in the gas phase, based on Prof. Glarborg's reburning mechanism.

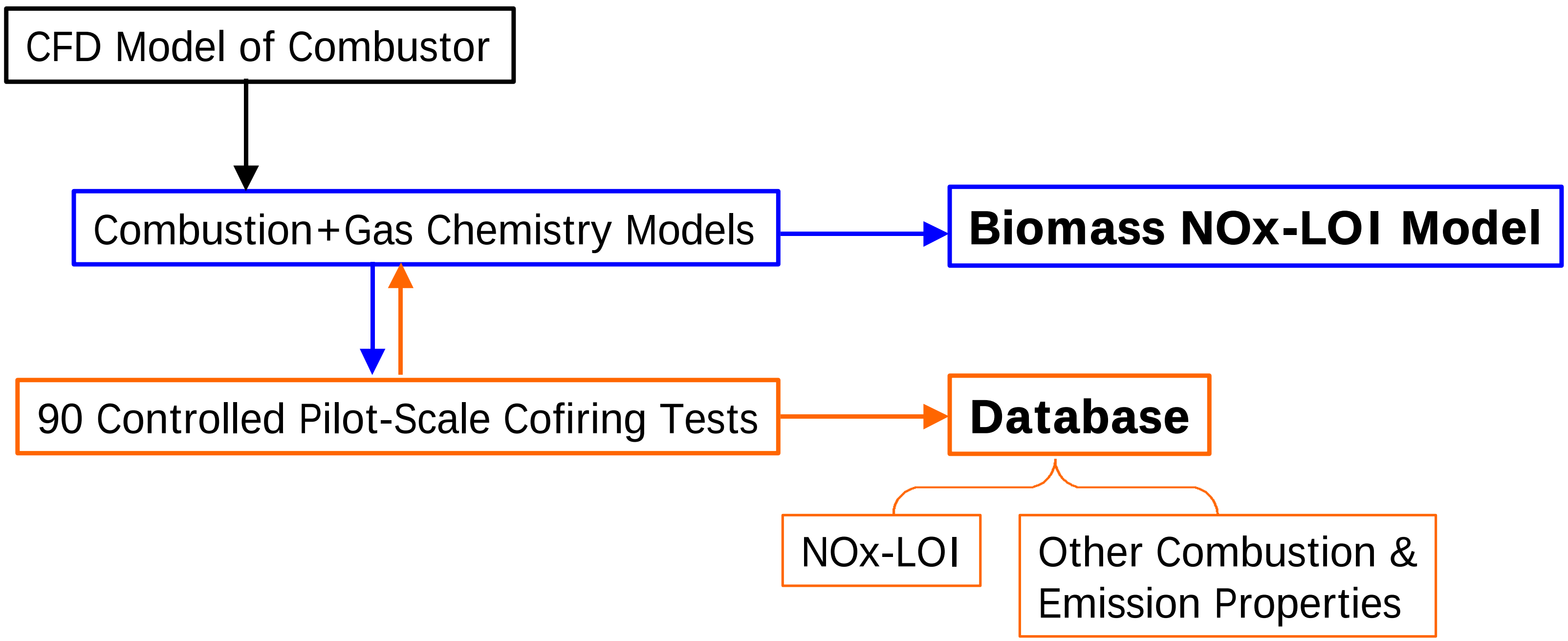
There Are No State-of-the-Art Modeling Tasks to be Resolved

- NEA has already used a hybrid equivalent network/CFD simulation to accurately predict NO_X from a full-scale coal-fired boiler.
- Bio-FC describes the complete distributions of major projects from any wood, grass, paper, and agricultural residue given on the PA and UA.
- CBK describes the latest stages of char burnout within useful quantitative tolerances.
- Fuel-N conversion based on 65 species and 358 elementary reactions.

Benefits of the Modeling

- Forecast change in emissions for a given fuel combination under a specified cofiring configuration.
- Identify the optimal cofiring configuration that minimizes emissions for a specified fuel composition.

Project Flow Chart



Project Schedule

ID	Task Name
1	**Project and Program Management**
2	NEPA Information
3	Project Management
4	Project Work Plan
5	**CFD Modeling**
6	Baseline furnace & burner
7	Parametric runs
8	**Simulation Tools Development**
9	Integrate bio-FLASHCHAIN & PC Coal Lab
10	Integrate PC Coal Lab & CHEMKIN III
11	Interpret CFD simulations for temperature profiles
12	Validation with coal-only cases
13	**Fuels Selection**
14	**Cofiring Tests in Combustion Research Facility**
33	**Model Simulations of Biomass Cofiring Cases**
34	Assign mixing parameters
53	Run simulations for all combinations of fuel & O2
72	**Reporting**
73	Quarterly Technical
81	Annual Report
84	Final Technical Report